The Problem

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With AMPS(S)
Arxiv: **1207.3132, 1304.6483, & 1307.4706**

- There is at present no case *for* firewalls per se. (E.g., no theory of how they form.)

- There *is* a problem. (This talk: Unitary BHs)
- Problem is serious. Appears to require “large” modifications of effective field theory at the horizon, though not outside the horizon. Proposed resolutions do not suffice. [TBD = To Be Debated]

- The Firewall hypothesis: We see no reason for such modifications to treat standard-model observers kindly. We therefore propose that something dramatic occurs at (typical or old) horizons, but that the effect outside the horizon is minimal. To be concrete, it can be interesting to discuss the simple picture of a Planck-scale (or lower-scale) burst of radiation (w/back-reaction) localized around the would-be horizon.

- We need a theory! (Joe’s talk)

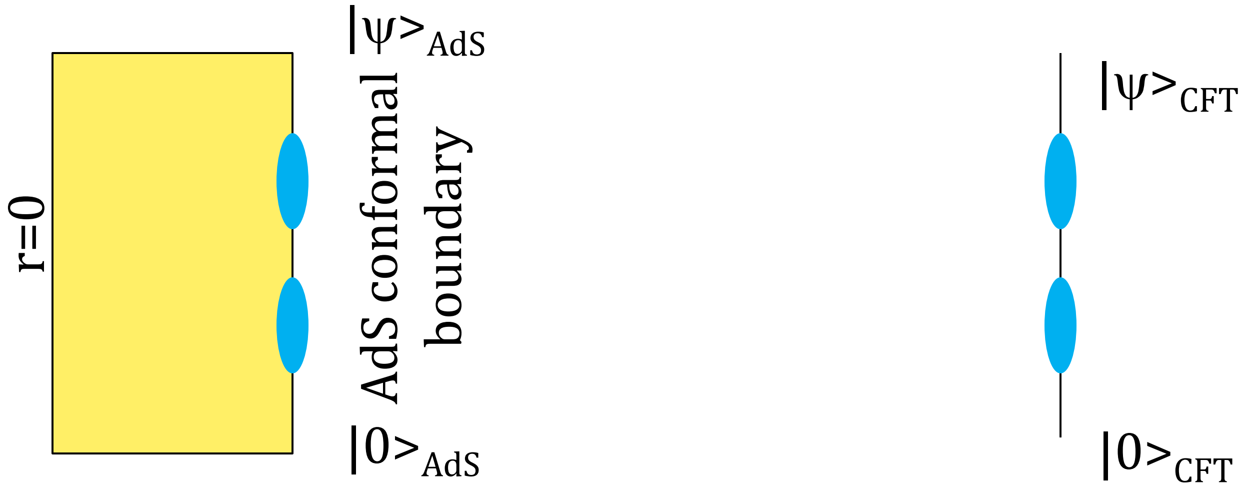
The problem is the finite density of states

EFT fails badly for typical states of the BH.

I'll present the argument as in 1307.4706:
Use AdS/CFT for maximum control,
though basic idea is more general. (See Raphael's talk).
Builds on earlier work with AMPS(S). See also Avery, Chowdhuri, & Puhm.
(And there are many earlier statements of similar problems.)

Note: We do not assume that CFT encodes "all" bulk physics.

AdS/CFT review



Asympt AdS space $|0>_{AdS} \Leftrightarrow |0>_{CFT}$ Dual CFT

If we couple sources to the CFT, the state evolves away from |0>. With enough care, we can make any CFT state.

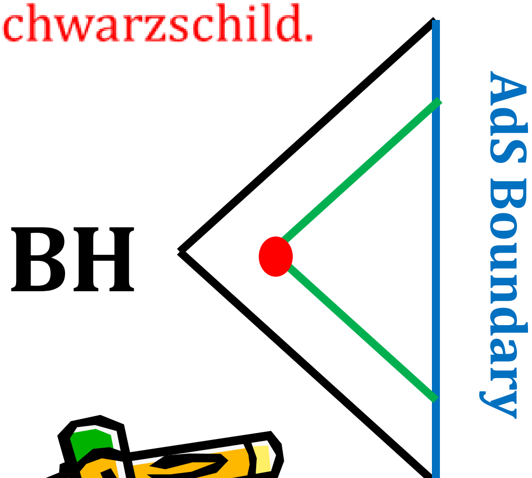
This is dual to making the AdS boundary conditions time-dependent, adding/remove energy through the conformal boundary.

Read backwards: Any AdS state (and any AdS black hole) made by using sources to add/remove radiation at the boundary is dual to a pure state in the CFT. We say that such states are formed by (perhaps exponentially slow!) “collapse.”

The problem is the finite density of states

Let ρ be the ensemble of collapse-states with $E \in (\bar{E} - \epsilon, \bar{E} + \epsilon)$.
Dual to CFT microcanonical ensemble.
Defines small Hilbert space $\mathcal{H}_E$.
Take $\epsilon \sim T_{Hawking}(\bar{E})$ or less.

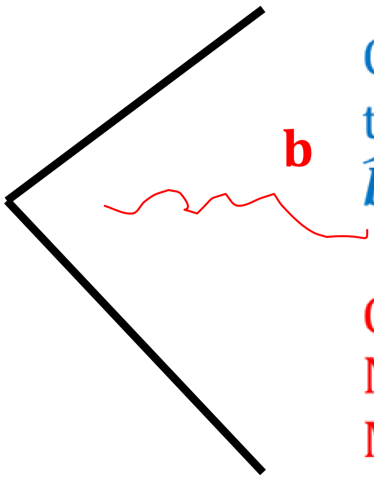
Assume this ensemble is dominated by (very close to) equilibrium BHs.
(Standard part of AdS/CFT, justified by entropy calculations if E not tiny.)
If EFT is valid, physics of $\mathcal{H}_E$. should be described by EFT on AdS-Schwarzschild.



Local operators outside the horizon can be written in terms of operators at the AdS boundary* (HLLK). Thus they act on collapse Hilbert space. Well defined in H_E (with small modifications) if commutator with H is small.

* Must work hard to do so for high j modes close to the horizon. But can do so for $N = \infty$. Should better explore finite N issues for high j, but CFT clearly has high density of states at large j. So expect no problems.

Single mode problem



Consider an approximate eigenmode **b** of of ∂_t in this background and the dual CFT operators $\hat{\boldsymbol{b}}, \hat{\boldsymbol{b}}^\dagger$, & $N_b = \widehat{\boldsymbol{b}^\dagger}\, \hat{\boldsymbol{b}}$.

Commutator of N_b and H is small, so to good approximation N_b acts within $\mathcal{H}_E$ and can be diagonalized in $\mathcal{H}_E$.
Min width of $\mathcal{H}_E$ is ~ $T/\ln(T_{Fire}L_{Planck})$, set by back-reaction of b.

Now consider a mode **a** that, using EFT, would describe excitations seen by appropriate freely-falling test observers crossing the horizon. Find N_a =0 only if our **b**-mode state is highly entangled with the state of some partner mode behind the horizon. (EFT)

Let **P** project onto $N_a > 0$.
Note that <**P**> = O(1) in any N_b-eigenstate.

So $< P >_{\mathcal{H}E} = \dfrac{Tr\ P}{Tr\ 1}$ = O(1) and an O(1) fraction of states in $\mathcal{H}_E$ have $N_a > 0$.

Multi-mode problem

Distinct modes are independent, so typical states have $N_a > 0$ for an O(1) fraction of modes **a**.

Large effect near horizon due to blueshift. Breakdown of EFT. "Firewall."

This is the problem.

In particular, no room for BHC to save the day.

Why does EFT correctly predict $S = S_{BH}$ and $T = T_{BH}$?

(Related to Mathur et al)

Maldacena: In AdS/CFT The CFT path integral computes

$$|\Psi> = \Sigma\ |E>\ |E>$$

Dual to some bulk state with 2 bndy's. (2-sided BH in semi-classical approx).

Exact t-trans symmetry $\uparrow\downarrow$.

So bulk either i) Always has a firewall

ii) Never has a firewall

We see no inconsistency with (ii). [DM & A. Wall]

Note: does not evolve to a generic CFT x CFT state
since the two E's are precisely correlated.

Suggests: Thermodynamically stable BH's with exact t-trans symmetry are firewall free.

E.g. even for $\Lambda = 0$ BH's in a box.

If so, semi-classical methods give correct results for thermo.

Implications for astrophysical BH's?

(I will assume that we can extrapolate freely from AdS/CFT.)

Do astro BH's evolve to approximate typical states?

Plausible hypothesis: BH acts like a typical state after scrambling time R ln R and develops a "Firewall".

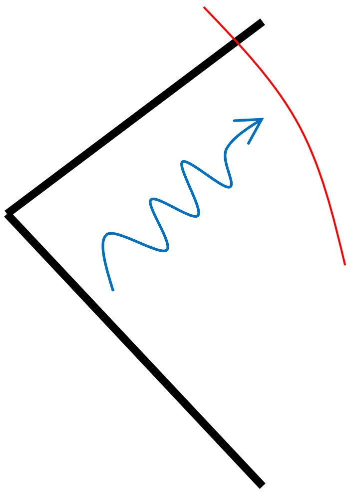
Tighter argument: Suppose that BH is a well-defined system, separate from the Hawking radiation. If BH's von Neumann entropy follows Page's curve (random state model), then $\rho \cong 1$ $(identity\ matrix)$ after the Page time. Firewall.

Avoiding $\rho \cong 1$ requires $S_{\text{Hawk Rad}}(t) < S_{\text{BH}}(t)$ at all times. Significant purification of the Hawk Rad must begin even before t_{Page}. Problem in EFT, even with BHC. Firewall.

What are the consequences for infalling observers?

(Can absorbing energy rejuvenate a black hole? c.f. Mathur & Turton)

AMPS: Suppose EFT outside and that "stretched horizon" behaves causally. Then observer's energy doesn't matter.



If EFT is modified at some proper distance D from the BH, still find firewall at scale $T_{Fire} \sim 1/D$. Expect D small, so T_{Fire} big. And over what area?

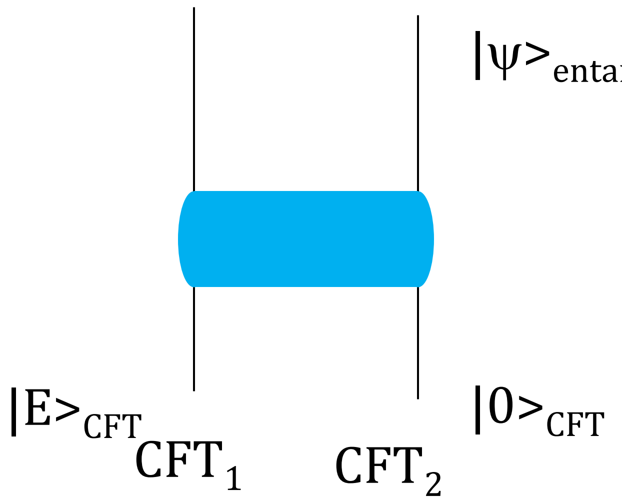
Example: Human falls into Sag A* BH.
Gravitational radii are $R_{BH} \sim 10^{10}$m, $R_{human} \sim 10^{-25}$m.
$L_{human} \sim 1$m

(3+1) Horizon shift outward suggests
$D \sim (R_{human}\, R_{BH})^{1/2} \ln[R_{BH}/L_{human}] \sim 10^{-6}$m.
Static-frame near IR photons that infaller encounters with massive boost!

Furthermore, expect
$A_{modified\ firewall} \sim L_{Planck}^2\, E/T \sim (R_{human}\, R_{BH}) \sim (D/10)^2 \sim 10^{-14}\mathrm{m}^2$.

AdS/CFT suggests that the BH can be a separate system.

$|\psi>_{entangled}$ w/ ρ_1 ~ canonical ~ microcanonical



Let the Boundary to Bulk map for a single CFT be Φ.

No one can stop me from constructing a bulk, both before and after the interaction, using $\Phi \otimes \Phi$.

Dual Description: Start with a large excitation of AdS (maybe a BH), but let the AdS-system interact with some system outside the AdS space. E.g., BH Hawking radiates and evaporates down to a smaller BH.

In equilibrium, AdS system will be in the microcanonical ensemble ρ_1 and will describe typical states.

Summary

- A finite density of BH states leads to severe problems for EFT in typical states.

- Problem is serious. Requires "large" modifications of effective field theory at the horizon, though not outside the horizon.

- Proposed resolutions do not suffice. [TBD = To Be Debated] So we propose firewalls or the like. But when (and how) do they turn on?

- Special states like the TFD may be firewall-free. This would explain the success of EFT predictions of S_{BH} & T_{BH}.

- We need a theory! (Joe's talk)